Wideband Feedback Systems

Full-Function Instability Control System

J.D. Fox[1]

LARP Ecloud Contributors:

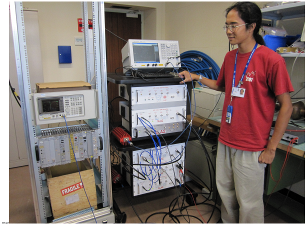
J. Cesaratto[1], J. Dusatko[1], J. D. Fox[1], J. Olsen[1], M. Pivi[1], K. Pollock[1], C. Rivetta[1], O. Turgut[1], S. Johnston[1]
G. Arduini[2],H. Bartosik[2], W. Hofle[2],G. Kotzian[2], K. Li[2],G. Rumolo[2], B. Salvant[2], U. Wehrle[2]
S. De Santis[3], H. Qian[3], Z. Paret[3]
D. Alesini[4], A. Drago[4], S. Gallo[4], F. Marcellini[4], M. Zobov[4]
M.Tobiyama[5]

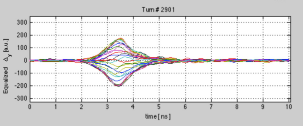
[1]Accelerator Research Department, SLAC
[2]BE-ABP-ICE Groups, CERN
[3]Lawrence Berkeley Laboratory
[4]LNF-INFN
[5]KEK

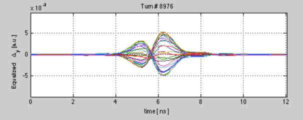
Review Charge and Why are we here?

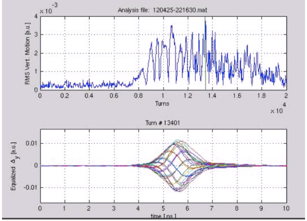
- Charge to the Review Committee for the Proposed LARP Project Scope and Plans
  - 1. Can the proposed project scope fit within the schedule and budget guidance given?
  - 2. Are the proposed cost, cost profiles and schedules reasonable?
  - 3. Is the plan to mitigate external schedule changes within the constraint of a fixed budget adequate?
  - 4. Is the technical plan proposed by each sub - project optimally developed? Are there additional technical risks that should be considered?
  - 5. Is the proposed management structure appropriate for the scope and scale of the project?
  - 6. Are there additional comments the Committee feels are relevant, regarding either individual tasks or the project as a whole?
- To Paraphrase the Talking Heads, "How Did We Get Here?"

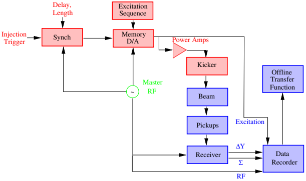
Beam Measurements, Simulation models, Technology development, Driven Beams and Demo System

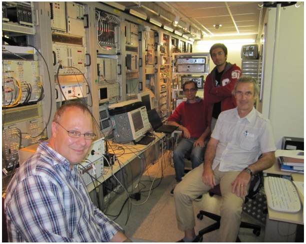












SPS Ecloud/TMCI Instability R&D Effort

- Stabilize Ecloud and TMCI effects via GHz bandwidth feedback
- Proton Machines, Ecloud driven instability - impacts SPS as high-current LHC injector (applicable also to LHC,PS)
  - Photoelectrons from synchrotron radiation - attracted to positive beam
  - Single bunch effect - head-tail (two stream) instability
- TMCI - Instability from degenerate transverse mode coupling - may impact high current SPS role as LHC injector
- Multi-lab effort - coordination on
  - Non-linear Simulation codes (LBL - CERN - SLAC)
  - Dynamics models/feedback models (SLAC - LBL-CERN)
  - Machine measurements- SPS MD (CERN - SLAC)
  - Kicker models and simulations (LNF-INFN,LBL, SLAC)
  - Hardware technology development (SLAC,KEK)
- Complementary to coatings, grooves, etc. for Ecloud control
- Also addresses TMCI, allows operational flexibility
- LARP feedback program provides novel beam diagnostics in conjunction with technology development

Wideband Intra-Bunch Feedback - Considerations

The Feedback System has to stabilize the bunch due to E-cloud or TMCI, for all operating conditions of the machine.

- unstable system- minimum gain required for stability
- E-cloud - Beam Dynamics changes with operating conditions of the machine, cycle (charge dependent tune shifts) - feedback filter bandwidth required for stability
- Acceleration - Energy Ramp has dynamics changes, synchronization issues (variation in β), injection/extraction transients
- Beam dynamics is nonlinear and time-varying (tunes, resonant frequencies, growth rates, modal patterns change dynamically in operation)
- Beam Signals - vertical information must be separated from longitudinal/horizontal signals, spurious beam signals and propagating modes in vacuum chamber
- Design must minimize noise injected by the feedback channel to the beam
- Receiver sensitivity vs. bandwidth? Horizontal/Vertical isolation?
- What sorts of Pickups and Kickers are appropriate? Scale of required amplifier power?
- Saturation effects? Impact of injection transients?
- Trade-offs in partitioning - overall design must optimize individual functions

Extensions from existing 500 MS/sec. architectures

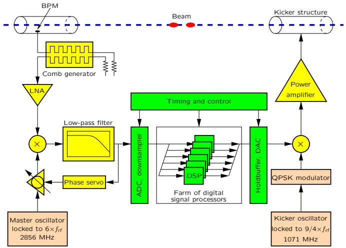
example/existing bunch-by-bunch feedback (PEP-II, KEKB, ALS, etc.)

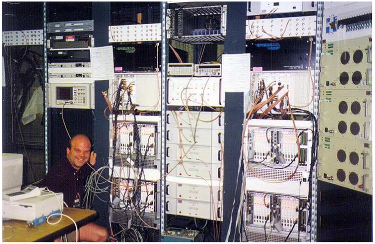
- Diagonal controller formalism
- Maximum loop gain from loop stability and group delay limits
- Maximum achievable instability damping from receiver noise floor limits

Electron-cloud effects act within a bunch (effectively a single-bunch instability) and also along a bunch train (coupling near neighbor bunches)

SPS and LHC needs may drive new processing schemes and architectures

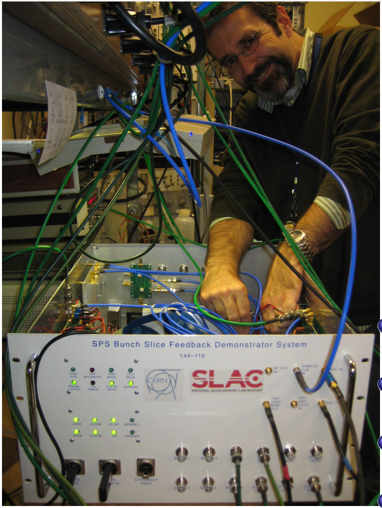
Existing Bunch-by-bunch (e/g diagonal controller) approaches may not be appropriate

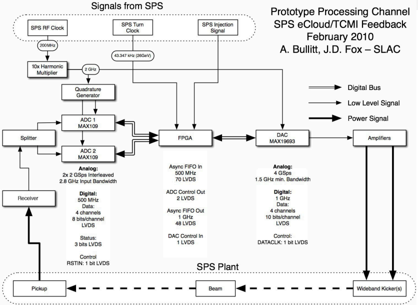




AY_008 HER and LER Electronics 10-4-97

4 Gs/sec. 1 bunch SPS Demonstrator channel





- Proof-of-principle channel for 1 bunch closed loop tests in SPS - commissioned November 2012
- Wideband control in SPS after LS1 (installation of wideband kicker)
- Reconfigurable processing - evaluate processing algorithms
- Technical formalism similar to 500 MS/sec feedback at PEP-II, KEKB, DAFNE

Demonstration 1 bunch processor

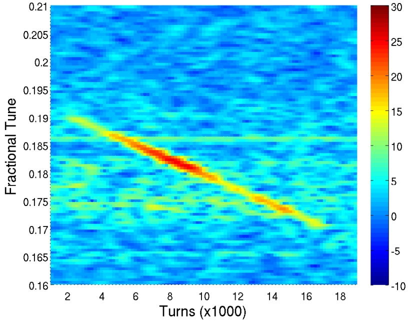
- Synchronized DSP processing system, initial 1 bunch controller
- Implements 16 independent control filters for each of 16 bunch “slices"
- Sampling rate 4 GS/sec. (3.2 in SPS tests)
- Each control filter is 16 tap FIR (general purpose)
- A/D and D/A channels
- Two sets of FIR filter coefficients, switchable on the fly
- Control and measurement software to synchronize to injection, manipulate the control filters at selected turns
- Diagnostic memories to study bunch motion, excite beams with arbitrary signals
- Reconfigurable FPGA technology, expand the system for control of multiple bunches
- What’s missing? A true wideband kicker. Technology in development. These studies use a 200MHz stripline pickup as a kicker

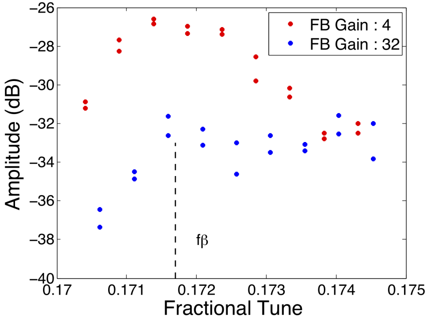
Recent MD Results Winter 2013

- MD trials (November, January, February) implement one-bunch feedback control
- 5 and 7 Tap FIR filters, gain variations of 30dB, Φ varied postive/negative
- Studies of loop stability, maximum and minimum gain
- Driven studies (Chirped excitations)
  - variation in feedback gain, filter paramters
  - multiple studies allow estimation of loop gain vs frequency (look at excitation level of several modes)
  - interesting to look at internal beam modes
- Feedback studies of naturally unstable beams

We are just starting to analyze data, a few examples to stimulate discussion

Driven Motion Studies- closed loop feedback

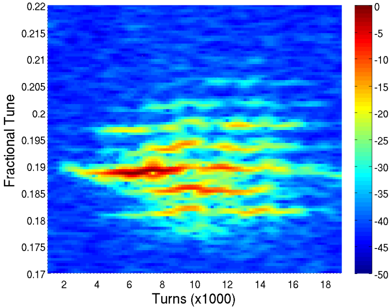




- Driven chirp Pickup spectrogram (left)
- Chirp tune 0.19 - 0.17 turns 2K - 17K
- Tune 0.183 (upper synchrotron sideband), Tune 0.175 Barycentric Mode
- Variation in Mode Zero Amplitude vs. loop gain (right)
- Study changes in dynamics with feedback as change in driven response

Positive Feedback Excitation of Internal Modes

- We need to characterize the response of the combined beam-feedback system
- Drive the beam using excitation chirps
- Vary the feedback gain and phase.
- Beam response shows effect of feedback on beam dynamics

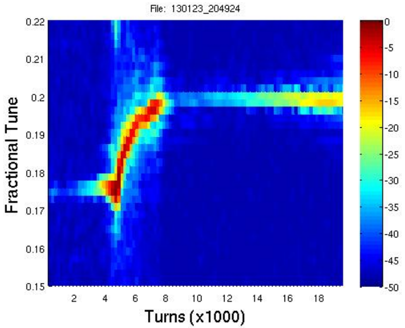


- An example spectrogram of unstable excited beam from the Feb 2013 MD
- ADC Input signal, positive feedback excitation turns 4000 to 12000 gain increased x4.
- turns 0 - 4k Negative FB, Positive turns 4K-12K, negative turns 12K - 20K

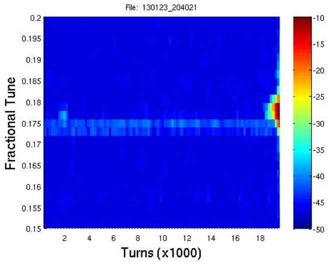
Example feedback control of unstable beam

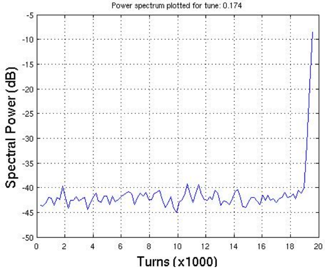
- SPS Cycle with chromaticity sweep to low (zero?) chromaticity after 1 sec into the cycle
- charge 1×10^{11} with slightly negative chromaticity
- With no FB the bunch is mode zero unstable (loses charge, seen in SUM signal and tune shift)
- Feedback was applied to beam after 2k (46 ms) turns, for a duration of 16 k turns
- Similar FIR filter design, ϕ = 90°, G = 32.
- Stabilization of the dipole mode is clearly shown during the 16k turns when FB is ON
- The beam motion grows when the FB is switched off as shown at the end of the data recording, turns 18k – 20k.

Feedback control of beam



- Spectrograms of bunch motion, nominal tune 0.175
- after chromaticity ramp at turn 4k, bunch begins to lose charge and gets tune shift.
- Feedback OFF -Bunch is unstable in mode zero (barycentric).



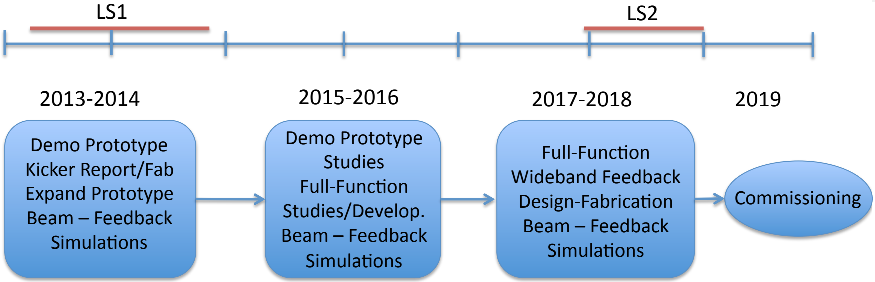


Feedback is switched off at turn 18K, beam then is unstable

Near Term Research and Technology Plans

- Existing 1 bunch Demo System
  - FY13 - FY14 Expand processing capabilites, add synchronization, other features (SLAC)
  - FY13 - FY14 Fabrication of wideband Transverse Kicker proof of principle prototype (CERN and LNF)
  - FY15 - FY16 Tests of 1 bunch demo with wideband kicker
- How is the "full-function" Deliverable different from the "Demo System"? From a "production system"?
  - Demo System -initial capabilities to explore single bunch dynamics, explore control algorithms,limited bandwidth kicker
  - Demo System - to be used with proof of principle wideband kicker, validate control capabilities
  - "Full-function" capability to control full ring, energy ramp, injection flexibility, operational interface
  - "Production System" - final operational hardware, with necessary upgrades and modifications learned from running "Full-Function"

Research and Technology Timeline



- Demo Commissioned
- MDs Jan.-Feb. 2013
- Kicker Design, Fabrication and Installation
- Data Analysis, Models and Simulation Tools
- Expand Hardware Capability
- MDs with new Hardware

- MDs with new hardware
- Multi-bunch operation
- Data analysis, models and simulation tools
- System specifications and capabilities
- Full-function Wideband Feedback Technology Development.

- Full-Function Wideband Feedback Design-Fabrication
- Continue MD studies
- Validate Energy Ramp
- Analysis, models and simulation tools

- System Integration
- Full interface with CERN Control Room
- Estimation of System Limits and Performance
- LHC? PS? SPS?

- Essential goal - be ready at end of LS2 with full-function system ready to commission
- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- We must use the demo system, MD time post LS1 to validate control ideas, validate kicker and technical approach. Full Function is only 1 design iteration away from Demo System

FY2013/2014 Development path - Research Areas

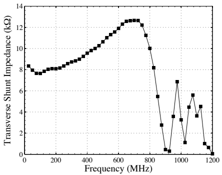
- During LS1 shutdown interval
- Expand Demo system (M&S costs in FY2012 $)
  - Low-noise transverse coordinate receivers,orbit offset and pickup techniques ($25K)
  - Wideband Kicker Prototype for SPS Installation LS1 (CERN supported LNF fabrication)
  - Expand Master Oscillator, Timing system to synchronize to the SPS RF system, Energy ramp control ($25K)
  - Expand firmware, design multi-bunch control, explore orbit offset/dynamic range improvements
- Diagnostic and beam instrumentation techniques to optimize feedback parameters and understand system effectiveness
- Continued simulation and modelling effort, compare MD results with simulations, explore new controllers

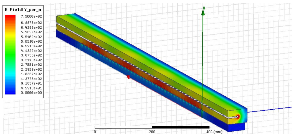
Ecloud/TMCI Wideband Feedback "Full-Function Deliverable"

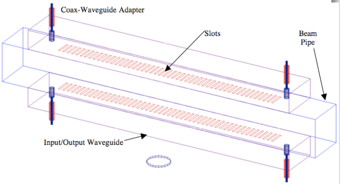
- Full-Function deliverable completed in FY18 for commissioning in FY19
  - "Full-Function" - capability to control full ring at high intensity
  - "Full-Function" - synchronization during energy ramping
  - Integration of system control/beam diagnostics for operation
- System capability to control full SPS ring at HL upgraded intensity
  - Beam line pickups/kickers
  - Beam motion receiver, processing electronics
  - 4 - 8 Gs/sec DSP for intra-bunch feedback
  - System Timing, Synchronization Clocks/Oscillators
  - GHz bandwidth Kicker(s), Power Amplifiers
  - Operator interfaces, control/monitoring software
  - Beam diagnostic software, configuration software
  - Accelerator Dynamics models, Stability tools
- Areas of SLAC/CERN contributions
  - SLAC - Feedback signal processing and control software, diagnostic software
  - CERN - tunnel based vacuum Components (kickers) and cable plant
  - Opportunity for collaborative engineering team, shared operational expertise

Kicker Options Design Study (J. Cesaratto)

- LNF-INFN,LBL and SLAC Collaboration. Excellent progress 2012-2013
- Goals - evaluate 3 possible options. Design Report June 2013
- Based on requirements from feedback simulations, shunt impedance, overall complexity - Provide CERN with a recommendation of which kicker technologies to fabricate.







CERN Contributions and SPS Plans

- Material from Wolfgang Hofle

Full-Function Wideband Feedback LARP Deliverables

- FY15 - FY16 Design studies Full-Function System
  - Simulation of full-function control algorithm, multi-bunch and multi-stack
  - System specification, capability specification, in conjunction with Demo System MD measurements
- FY17 - FY 18 Full-Function System design and fabrication
  - "Full-Function" capability for all bunches in SPS, energy ramp, operational flexibility (e.g. 10 ns scrubbing fill, flexible SPS cycles)
  - Operational interface, control path to CERN CCR
  - "Full-Function" implementation anticipates operational needs and capabilities as indicated from tests with 1 bunch Demo system
- FY19 - reduced manpower to commission/test system at SPS after LS2
- SLAC's contribution - all low-level signal processing, DSP functions, synchronization functions, operational interface
- CERN's contribution - All vacuum structures (pickup, low and high band kickers) all tunnel cable plant
- Potential shared contributions - High Power kicker amplifiers (low band, high band)

FY2015/2016 Research plans, Technology development path, M&S plans (M&S costs FY2012 $)

- MD measurements with wideband DEMO system (SPS beam time and analysis)
  - Diagnostic and beam instrumentation techniques to optimize feedback parameters and understand system effectiveness
  - Continued simulation and modelling effort, compare MD results with simulations, explore new controllers
  - Evaluate options for Kickers (wideband? dual band?) and upgrade tunnel High-Power wideband RF amplifiers for SPS operation ($50K)
- Technology Development and system estimation for Full-function system
  - Wideband 20 - 1000 MHz RF power amplifiers, with acceptable phase response ($75K)
  - RF Support for SPS tests ($25K)
- High-speed DSP Platform consistent with 4 -8 GS/sec sampling rates for full SPS implementation ($75K)
  - lab evaluation and firmware development
  - estimation of possible bandwidths, technology options for deliverable

FY2017/2018 Technology development path, M&S Plans (M&S costs FY2012 $)

- FY2017 Continued Demo System Dynamics R&D
- FY2017/2018 Development of Full-function system deliverable (LS2 2018)
  - Beam Motion receiver ($50K)
  - Dynamic range preservation (orbit offset) processor ($30K)
  - Front-end delay, timing and synchronization methods ($20K)
  - SPS Timing System operational interface ($20K)
  - FPGA Main processing logic motherboard ($100K)
  - Front End A/D System (4-8 GS/s) ($20K)
  - Back End D/A System (4-8 GS/s rate) ($20K)
  - Back End low level distribution, band split, fanout and timing ($40K)
  - Back End Power Amplifiers (total $200K)
  - High-Power couplers, monitoring and diagnostic mux systems ($40K)
  - User interface processor and firmware for operations ($35K)
  - Lab hardware, engineering model components (future critical spares) ($75K)

FY2019 Research and Commissioning Plans

- Post LS2 Commission SPS Full-function Wideband Feedback system deliverable
  - MD measurements, analysis
  - Publication of research results (Grad student thesis)
  - Adaptation of Demo system for PS test/use
  - Specification of LHC system, LHC system proposal
- Commissioning effort is joint SLAC/CERN activity, allows CERN to develop operational expertise, investment in implementation technology
- (Possible transfer of Demo system to PS for development and MD studies)

Manpower and Skills Overview

- Necessary Skills and Capabilities
  - Accelerator modelling and dynamics
  - MD measurements and data analysis
  - Control theory and techniques
  - Wideband RF (pickups, kickers, beam motion receivers)
  - GS/s Digital signal processing
  - Project management and planning
- Manpower
  - SLAC based - signal processing contributions
    - Staff Physicists and Engineers
    - Toohig Fellow and/or Postdoctoral Research Associate
    - Graduate Students
  - CERN based
    - MD coordination
    - Potential firmware contribution
  - Kicker Structures and Tunnel cable plant
    - CERN funded, CERN managed
    - Design report with SLAC/LBL/LNF authors
    - LNF to fabricate prototype under LIU HL program

Manpower - Research vs. Deliverable System Development

- Rationale by skill set, numbers and year 13-14, 15-16,17-18
- Balance between research/education component (grad students, Fellow) vs. Simulation/dynamics effort , Engineering skills required
- Possible coordination with CERN Engineering and Accelerator Physics skills
  - DSP firmware (SLAC and CERN)
  - Pickup and Kicker implementation (CERN and LNF)
  - Front end, Receiver (SLAC)
  - Master Oscillator, Timing system (SLAC and CERN)
  - Back end, Power stages (SLAC and CERN)
  - Diagnostic and beam motion analysis techniques (SLAC, CERN and LNF)
  - Nonlinear Beam and Feedback Simulations (CERN and SLAC)

FULL FUNCTION DELIVERABLE - HIGH BANDWIDTH INTRA-BUNCH INSTABILITY FEEDBACK SYSTEMS Full function deliverable available for test after LS2
Revision #1.3 J. Cesaratto, J. Fox, C. Rivetta , based on 1 full function deliverable and "supplied" SLAC labor rates
Revision Date: 06/06/2012

Brief Scope Description and Assumptions.

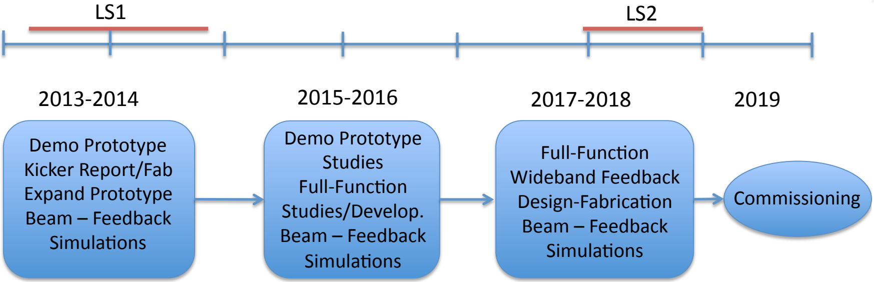
	FY12 BASE	FY13 (LS1)	FY14 (LS1)	FY15	FY16	FY17	FY18 (LS2)	FY19	FY20	FY21	FY22 (LS3)	Total w/o Contingency	Contingency %	Total incl. Contingency
M&S Escalation		2.70%	5.47%	8.32%	11.24%	14.24%	17.32%	20.49%	23.74%	27.08%	30.51%			
Labor Escalation		0.80%	2.82%	5.39%	8.02%	10.72%	13.49%	16.33%	19.24%	22.16%	25.27%			
DEVELOPMENT/EXPANSION of DEMONSTRATION PROCESSING SYSTEM														
M&S	**$100,000**	**$0**	**$52,735**	**$54,160**								**$106,895**		**$141,636**
Synchronization function for energy ramp	$25,000	$0	$26,368									$26,368	33%	$34,937
Reciever channel development, prototype	$25,000	$0	$26,368									$26,368	33%	$34,937
High bandwidth kicker power amplifiers,splitters/combiners	$50,000	$0	$0	$54,160								$54,160	33%	$71,762
Wideband slotline kicker prototype	$62,500	$64,188	$65,919									$130,106	33%	$173,041
LABOR	**$975,000**	**$982,800**	**$1,002,495**									**$1,985,295**		**$1,985,295**
Staff Scientist, 2 FTE	$600,000	$604,800	$616,920									$1,221,720	0%	$1,221,720
Staff Engineer, 1 FTE	$280,000	$282,240	$287,896									$570,136	0%	$570,136
Fellow/Postdoc, 1 FTE	$180,000	$181,440	$185,076									$366,516	0%	$366,516
Graduate Student, 2 FTE (50% cost split with SLAC)	$95,000	$95,760	$97,679									$193,439	0%	$193,439
DESIGN STUDIES OF FULL-FUNCTION PROTOTYPE, SIMULATIONS, MDs with 1 bunch Demo														
M&S	**$175,000**			**$108,320**	**$83,430**							**$191,750**		**$254,069**
High power amplifiers for SPS MD evaluation	$75,000			$81,240	$0							$81,240	33%	$107,643
RF components, control equipment for kicker and power amplifiers	$25,000			$27,080	$0							$27,080	33%	$35,881
High capacity processing channel development, 2nd FPGA platform for development	$75,000			$0	$83,430							$83,430	33%	$110,545
LABOR	**$1,120,000**			**$1,180,368**	**$1,209,824**							**$2,390,192**		**$2,868,230**
Staff Scientist, 2.25 FTE	$675,000			$711,383	$729,135							$1,440,518	20%	$1,728,621
Staff Engineer, 1.25 FTE	$350,000			$368,865	$378,070							$746,935	20%	$896,322
Fellow/Postdoc, 1.5 FTE	$270,000			$284,553	$291,654							$576,207	20%	$691,448
Graduate Student, 2 FTE	$95,000			$100,121	$102,619							$202,740	20%	$243,287
DESIGN and FABRICATION OF A FULL-FUNCTION DELIVERABLE with CONTROL INTERFACE														
M&S (cost per system, based on one system)	**$710,000**					**$391,272**	**$519,141**					**$910,413**		**$1,365,620**
Front end hybrid and beam motion receiver	$50,000					$57,120	$0					$57,120	50%	$85,680
Orbit-offset and dynamic range preservation processor	$30,000					$34,272	$0					$34,272	50%	$51,408
Front end variable delay and timing alignment	$20,000					$0	$23,464					$23,464	50%	$35,196
Timing and synchronization system for interface to accelerator	$20,000					$11,424	$11,732					$23,156	50%	$34,734
FPGA signal processing channel (logic processing functions)	$100,000					$0	$117,320					$117,320	50%	$175,980
Front end A/D system for 4 GS/s rate	$20,000					$0	$23,464					$23,464	50%	$35,196
Back end D/A system for 4 GS/s operation	$20,000					$0	$23,464					$23,464	50%	$35,196
Back end low level distribution, band split, fanout and timing distrubution chassis	$40,000					$0	$46,928					$46,928	50%	$70,392
Back end power amplifiers, 4 low band, 100 W each	$100,000					$0	$117,320					$117,320	50%	$175,980
Back end power amplifiers, 4 high band, 100 W each	$160,000					$182,784	$0					$182,784	50%	$274,176
High power couplers, monitoring, and diagnostic mux subsystem	$40,000					$0	$46,928					$46,928	50%	$70,392
User interface processor and firmware for operator	$35,000					$19,992	$20,531					$40,523	50%	$60,785
Critical spare components for operation	$75,000					$85,680	$87,990					$173,670	50%	$260,505
OPTIONAL ITEMS (cost per system, based on one system)	**$570,000**					**$314,160**	**$346,094**					**$660,254**		**$990,381**
Tunnel cables, high and low power	$25,000					$0	$29,330					$29,330	50%	$43,995
Tunnel racks, cooling, and power distribution, monitoring	$20,000					$0	$23,464					$23,464	50%	$35,196
Pickup structure (including feedthroughs and vacuum structure)	$75,000					$85,680	$0					$85,680	50%	$128,520
Low band kicker assemblies (including feedthroughs - 2 each and vacuum structure)	$200,000					$228,480	$0					$228,480	50%	$342,720
High band kicker assemblies (including feedthroughs - 2 each and vacuum structure)	$250,000					$0	$293,300					$293,300	50%	$439,950
LABOR	**$1,255,000**					**$1,389,536**	**$1,424,300**	**$878,292**				**$3,692,127**		**$5,168,978**
Staff Scientist, 2 FTE	$600,000					$664,320	$680,940	$523,485				$1,868,745	40%	$2,616,243
SLAC Staff Engineer, 2 FTE	$560,000					$620,032	$635,544	$244,293				$1,499,869	40%	$2,099,817
CERN Staff Engineer	$280,000					$310,016	$317,772	$162,862				$790,650	40%	$1,106,910
Fellow/Postdoc, 1.5 FTE	$270,000					$298,944	$306,423	$209,394				$814,761	40%	$1,140,665
Graduate Student, 2 FTE	$95,000					$105,184	$107,816	$110,514				$323,513	40%	$452,918
TRAVEL (By year with escalation (labor rate) and overhead)	**$42,500**	**$65,365**	**$66,224**	**$67,316**	**$68,434**	**$73,674**	**$74,921**	**$76,199**				**$492,131**		**$492,131**
Total (for 1 delivered full-function system), no CERN contribution		$1,293,793	$1,372,448	$1,694,717	$1,653,342	$2,777,602	$2,988,650	$1,326,746				$13,107,297		**$16,571,879**
Total (for 1 delivered system to the SPS), w/CERN contribution		$1,048,165	$1,121,454	$1,410,164	$1,361,688	$1,854,482	$2,018,361	$954,490				$9,768,803		**$12,275,958**

LABOR RATES: (Including benefits and 53% indirect)	
Staff Scientist	$300,000
Staff Engineer	$280,000
Postdoc	$180,000
Graduate Student (50% LARP, 50% SLAC ARD support)	$95,000

M&S overhead rate 7.65% per Cole Carter	7.65%
Travel overhead rate at the G&A labor rate of 53%	53%

NOTES:
Lines highlighted in peach correspond to potential CERN contribution
Lines highlighted in green correspond to LARP contribution
Lines highlighted w/pattern correspond to cost split or potential CERN contribution
Contingency catagories listed in proposal document, % here are averaged over assigned line tasks
Travel costs escalated with labor rate. What is travel escalation rate?
CERN costs estimated using typical US Lab costs.
Total, CERN contribution assumes CERN provides for the OPTIONAL ITEMS (e.g., vacuum kickers, pickups, cabling, etc.)
CERN Fellow/Postdoc (E.g., K. Li) works on mix of simulation and hardware development
Graduate students 50% LARP, 50% ARD SLAC support

Project Timeline



- Demo Commissioned
- MDs Jan.-Feb. 2013
- Kicker Design, Fabrication and Installation
- Data Analysis, Models and Simulation Tools
- Expand Hardware Capability
- MDs with new Hardware

- MDs with new hardware
- Multi-bunch operation
- Data analysis, models and simulation tools
- System specifications and capabilities
- Full-function Wideband Feedback Technology Development.

- Full-Function Wideband Feedback Design-Fabrication
- Continue MD studies
- Validate Energy Ramp
- Analysis, models and simulation tools

- System Integration
- Full interface with CERN Control Room
- Estimation of System Limits and Performance
- LHC? PS? SPS?

- Essential goal - be ready at end of LS2 with full-function system ready to commission
- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- We must use the demo system, MD time post LS1 to validate control ideas, validate kicker and technical approach. Full Function is only 1 design iteration away from Demo System

Labor Cost Methodology

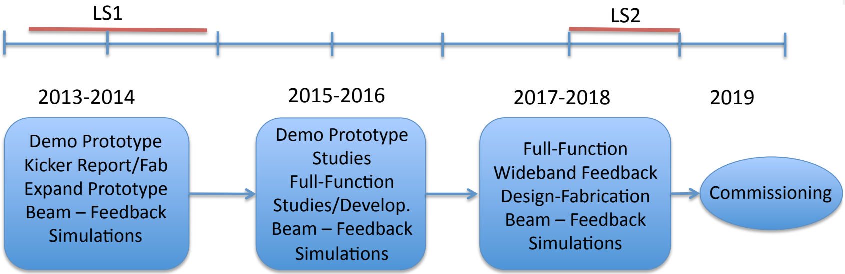
- Labor costs based on SLAC overhead and numbers from representative typical rates
- Mix of Student/fellow contributions, Lab Staff (physicist/engineer) contributions
- 50% grad student support, 50% assumed support from SLAC ARD GARD funds
- Would benefit from availability of Toohig Fellow (but as extra manpower)
- Does not include any LBL, LNF or CERN manpower as a LARP cost
- Costs include escalation and contingency per DOE model

Manpower Timeline

2013-2014	2015-2016	2017-2018	2019
Demo Prototype Kicker Report/Fab Expand Prototype Beam – Feedback Simulations	Demo Prototype Studies Full-Function Studies/Develop. Beam – Feedback Simulations	Full-Function Wideband Feedback Design-Fabrication Beam – Feedback Simulations	Commissioning
• SLAC • 2 FTE Physicist • 1 FTE Engineer • 2 - 50% RA students • CERN • 1 FTE Simulation/ Engineering	• SLAC • 2.25 FTE Physicist • 1.25 FTE Engineer • 2 - 50% RA students • CERN • 2.5 FTE Simulation / Engineering / MD studies	• SLAC • 2 FTE Physicist • 2 FTE Engineer • 2 - 50% RA students • CERN • 2.5 FTE Simulation / Engineering / MD studies	• SLAC • 1.5 FTE Physicist • 0.75 FTE Engineer • 2 - 50% RA students • CERN • 2 FTE Simulation / Engineering / Commission

- Essential goal - be ready at end of LS2 with full-function system ready to commission
- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- We must use the demo system, MD time post LS1 to validate control ideas, validate kicker and technical approach. Full Function is only 1 design iteration away from Demo System

Manpower Timeline



- SLAC(Actual'13)
- 1.25 FTE Physicist
- 0.3 FTE Engineer
- 2 - 50% RA students
- LBNL
- 0.35 FTE Physicist
- CERN
- 1 FTE Simulation/ Engineering

- SLAC
- 2 FTE Physicist
- 1 FTE Engineer
- 2 - 50% RA students
- CERN
- 1 FTE Simulation/ Engineering

- SLAC
- 2.25 FTE Physicist
- 1.25 FTE Engineer
- 2 - 50% RA students
- CERN
- 2.5 FTE Simulation / Engineering / MD studies

- SLAC
- 2 FTE Physicist
- 2 FTE Engineer
- 2 - 50% RA students
- CERN
- 2.5 FTE Simulation / Engineering / MD studies

- SLAC
- 1.5 FTE Physicist
- 0.75 FTE Engineer
- 2 - 50% RA students
- CERN
- 2 FTE Simulation / Engineering / Commission

- Essential goal - be ready at end of LS2 with full-function system ready to commission
- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- We must use the demo system, MD time post LS1 to validate control ideas, validate kicker and technical approach. Full Function is only 1 design iteration away from Demo System

Technology and System Development Cost Methodology

- Catalog prices for purchased items (eg power amplifiers, delay lines)
- Consistency with project technology development costs to date (fab of Demo and Excite systems)
- System capabilities estimated based on best knowledge from simulations, MD results and experience
- Plan for deliverable system, engineering model will become spare for operations
- Costs include escalation and contingency per DOE model

Other costs carried in budget

- Travel for MD measurements, conferences, accelerator schools
- Lab equipment (e.g. test/measurement necessary for design/evaluation, prototype hardware evaluations, MD instrumentation, software for E&M design and FPGA design) - TBD amounts, partial split with GARD funds

Risks and Mitigation

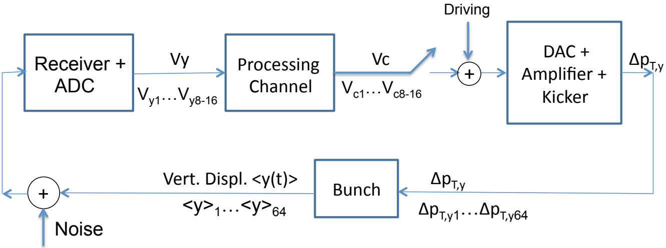
- Successful 1 bunch Demo and initial MD effort is excellent start to show ability to meet schedule requirements and technical competence
- Technical Risks - Uncertainty in required bandwidth, control methods for non-linear system, complexity/type of control algorithm, necessary system power, etc.
  - Mitigations in reconfigurable FPGA algorithm, scalable power stages, possibility of adding extra kickers or multiple kicker technologies.
  - Confidence from post LS-1 multi-bunch tests, decision point before fab of full-function deliverable
- Demonstrated risk - underfunding of necessary FY13-14 effort
  - example, FY13 budget plan, underfunding of actual FY13 year
  - limitation of engineering contribution to 12.5% FTE
  - Guarantees project is late starting in FY14, loses important time this year to work on critical system capabilities (energy ramp, multi-bunch capability, etc.) necessary for post LS1 MD program.
  - FY14 amplifier evaluation pushed back into FY15 due to budget limits
  - Lack of manpower assignment authority means risk of loss of critical signal processing engineer, loss of continuity of project progress

Summary and Discussions

- "Full Function " as deliverable - original plan was to make PS, SPS and LHC production systems after full-function
- roughly 30% extra cost to make actual production systems based on operational experience from Full-function prototype
  - manpower is extremely lean for combined research and engineering effort
  - research aspect, Ph.D. students and new control ideas are inexpensive but not luxuries to be cut out to save $
  - System design is reconfigurable, allowing future improvements
  - Operational software, operator integration within CERN environment is potentially beyond scope of this deliverable
  - CERN interest in multiple systems for the PS , SPS and LHC
  - CERN interest in development of accelerator diagnostics as function within feedback channel
- Discussions with Reviewers
  - Project funding is 80% salaries, overheads - technical component is 13 - 20%
  - Realistic plans for FY 13, 14 - necessary timing and synchronization functions
  - importance of original FY13 and FY14 planning, including amplifier evaluations
  - Critical and vital installation of wideband kicker into SPS at end of LS1
  - Importance of MD program in FY15, modelling effort to verify control algorithms and system features

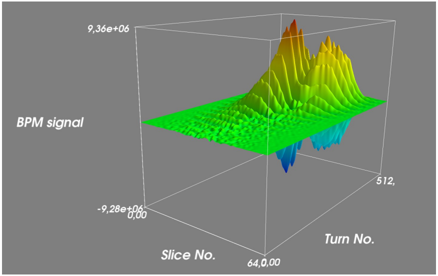
Progress in Simulation Models

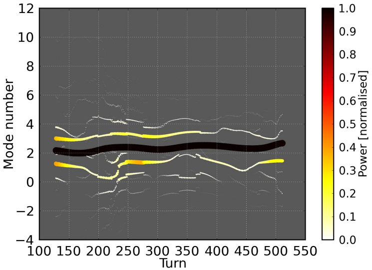
- Critical to validate simulations against MD data
- Still needs realistic channel noise study, sets power amp requirements
- Still needs more quantitative study of kicker bandwidth requirements
- Head-tail offers path to evaluate TMCI and feedback methods
- Continued progress on linear system estimation methods
- Model test bed for controller development



HeadTail study - Ecloud driven instability of SPS

Ecloud instability, 10^{11} protons/bunch, $\rho_e \approx 6 \times 10^{11} e^- m^{-3}$

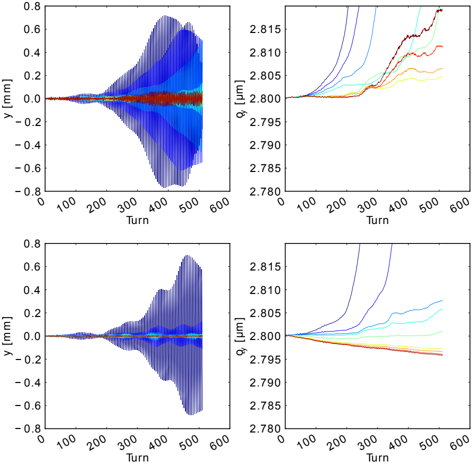




- Clear coherent motion above the instability threshold
- The mode evolution reveals the presence of predominantly modes {0, -1, -2} (shifted)

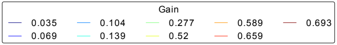
Macro-Particle Simulation Codes- HeadTail

- Electron cloud interaction with a bunch of 1.1×10^{11} protons.



Kicker $BW = 200$ MHz.

- Motion is unstable at all gain settings

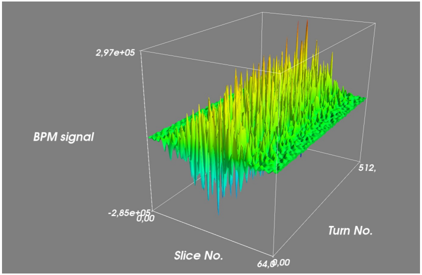


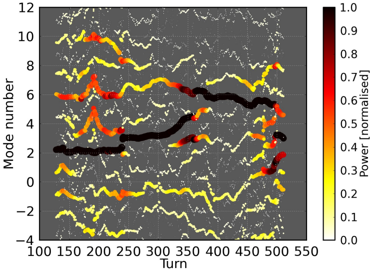
Kicker $BW = 500$ MHz.

- Evolution of the bunch centroid motion and the normalized emittance for different gains G.
- Motion is stable for gain > threshold
- Ecloud density $= 6 \times 10^{11} e/m^3$

HeadTail study - simplified feedback, 500 MHz Kicker

Ecloud instability, 10^{11} protons/bunch, $\rho_e \approx 6 \times 10^{11} e^- m^{-3}$





- Clear damping of the coherent motion
- Remaining power is distributed over modes {2,6}

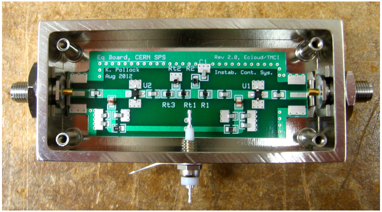
- Nonlinear system, difficult to quantify margins

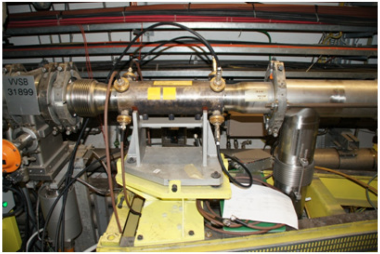
Technology Development for SPS tests

- Timing and synchronization master oscillator
- Beam Motion Receiver (delta/sigma system)
- 4(3.2) GS/sec. Beam excitation system (arbitrary waveform generator, 15K turns)
- 4(3.2) GS/sec. DSP Feedback Demo processor
- Tunnel amplifiers/control for beam excitation (4$\times$ 80W 1 GHz)

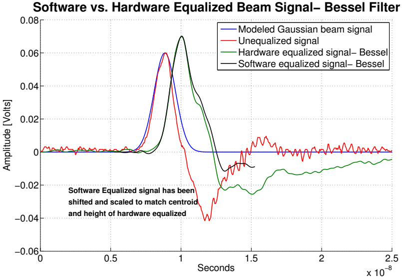
The goal is to build general purpose testbed components to allow machine measurements, experiments of fundamental control ideas using the SPS

Hardware Equalizer





- Pickup response distorts beam signals
- Long cables also have nonlinear phase response
- Existing software equalizer used in matlab data processing
- we need a real-time (hardware) equalizer for processing channel
- Optimzation technique - can be used for kicker. too



Feedback algorithm complexity and numeric scale

Frequency spectrograms suggest:

sampling rate of 2 - 4 GS/sec. (Nyquist limited sampling of the most unstable modes)

Scale of the numeric complexity in the DSP processing filter

- measured in Multiply/Accumulate operations (MACs)/sec.

SPS -5 GigaMacs/sec (6*72*16*16*43kHz)

- 16 samples/bunch per turn, 72 bunches/stack, 6 stacks/turn, 43 kHz revolution frequency
- 16 tap filter (each slice)

KEKB (existing iGp system) - 8 GigaMacs/sec.

- 1 sample/bunch per turn, 5120 bunches, 16 tap filters, 99 kHz revolution frequency .

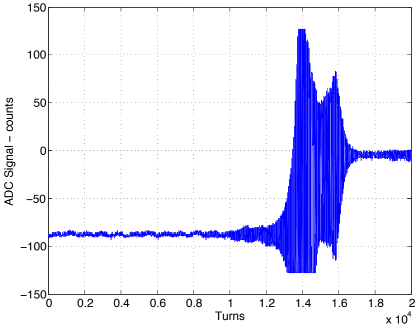
The scale of an FIR based control filter using the single-slice diagonal controller model is not very different than that achieved to date with the coupled-bunch systems.

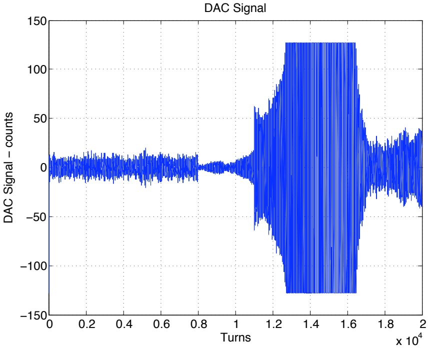
What is different is the required sampling rate and bandwidths of the pickup, kicker structures, plus the need to have very high instantaneous data rates, though the average data rates may be comparable.

MD Feedback studies on unstable or marginally stable beams

- Manipulate feedback parameters, study free beam responses
- Feedback control as time-varying parameter (on, off, variable gains, filters, Positive/Negative feedback etc.)
- Study changes in dynamics vs. feedback configuration (grow/damp studies)
- Manipulation of feedback filters allows growth of instability from stable controlled state, measurement in small-amplitude conditions
- Easily measures fastest modal growth rates - requires care to measure slow modes in presence of fast modes
- Disadvantage - requires feedback control to do most studies

Unstable beam -Input, Output signals via snapshot





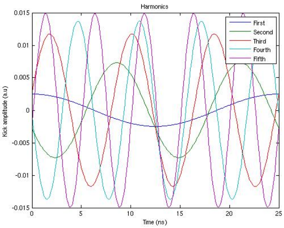
- Example of gain reduction during stable control, loss of control after gain restoration 3k turns later. Transient deserves more complete analysis.
- Mode zero unstable beam
- Gain modulated $\times 8$-$\times 2$-$\times 8$ during cycle
- For turns 0-8k, 8k-11k, 11k-end
- Input (left), DSP output (right) Note gain of filter,DC suppression and saturation

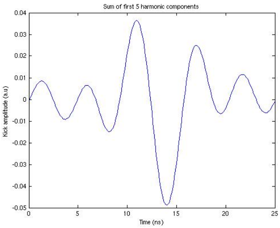
Future Directions - beam studies

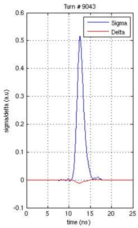
- The Demo platform is a reconfigurable testbed for control techniques
- Provides unique beam diagnostics and opportunities for new measurement methods
- Studies of unstable systems are difficult, control and time varying gain is a useful method (grow-damp techniques)
- To date, unstable beams available have had mode zero instabilities, we want to study higher internal modes
- Complementary methods with driven responses
- We are eager to collaborate on novel beam diagnostics and measurement techniques, analysis methods
- Analysis of recent MD transients will require some time, future talks and discussions

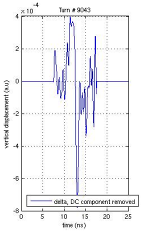
Implications from the 25ns bunch spacing

- Sandro’s note, Dmitry’s contributions - Basic themes
  - Correction signal is wideband in time scale of 2 ns bunch (head-tail, higher excitations)
  - 25 ns bunch interval - allows narrower bandwidth kickers, use 25 ns to get to full scale amplitude
  - Decompose kick into several fundemental "modes" - beam samples and integrates final kick
- Requires multiple output signals, calculation of "modes" vs. parallel scheme, requires multiple operational phasing and equalization requirements





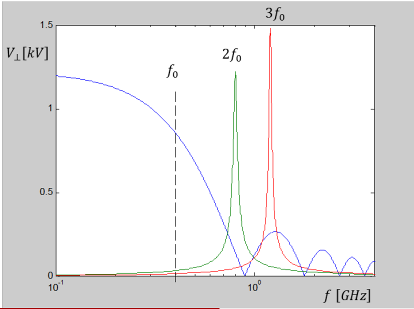




Kicker Options - Idea from S. Gallo

- Use 25 ns interval between bunches, have kicker with 20 ns fill time
- High shunt impedance, requires more complex off-diagonal processing, input and output data at different rates

	Kicker #1	Kicker #2	Kicker #3
Type	Stripline	Cavity, TM110 defl. mode	Cavity, TM110 defl. mode
3-dB bandwidth	DC – 400 MHz	800 ± 16 MHz	1200 ± 16 MHz
Length	17 cm	15 cm	10 cm
Filling time	0.6 ns	10 ns	10 ns
Q_l	---	25	38
Shunt Impedance	≈ 1.5 kΩ (@ DC)	≈ 1.5 kΩ (@ 800 MHz)	≈ 2.2 kΩ (@ 1200 MHz)



Assuming that each kicker is powered by a 1 kW source covering the entire device bandwidth, the resulting transverse voltage transferred to the beam as a function of the frequency is shown in the following plot.